FERMI NATIONAL ACCELERATOR LABORATORY

SILICON DETECTOR FACILITY:

TESTING SILICON DETECTORS FOR THE D0 EXPERIMENT USING LASER

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Abstract: The purpose of the paper is to explain the behavior and response of a silicon detector to an electrical signal. This pulse is simulated using a laser. Varying several parameters provides some visible changes in the behavior of the pulse generated in the sensor. Examples of such changes include the shape and height. Some of the parameters varied are the voltage, the pre-amp bandwidth and the pre-amp current.

Further explanations of these terminologies are available in subsequent sections of this paper. We were able to understand how the change in bandwidth and current settings affects the response and as well the noise in the detectors and what settings will yield optimum results during the run of the experiment.

Introduction: FERMI NATIONAL ACCELERATOR LABORATORY takes the understanding of the building blocks of our universe to another level. Research involving both collision of proton and anti-protons and even collision of a proton with a fixed metal target and analysis of the outcome is just a bit of the numerous experiments currently undergone at FERMILAB. The D0 experiment utilizes the D0 detector for experiments based mainly on proton-antiproton collision. It is aimed at answering some questions that are yet to be answered. It is hoped to provide signatures to some areas yet to be discovered in particle physics such as dark matter, dark energy, and super symmetry.

What are silicon detectors?

Detectors are semi-conductor devices that are used in a variety of applications in high-energy physics. They are popular due to their unmatched energy and spatial resolution, and they have a good response time. They are manufactured mainly of silicon.

In principle, if an ionizing particle penetrates the detector, it produces an electron-hole pair along its track; the number is always proportional to the energy loss. An external electric field separates the pairs before they re-combine; electrons drifting to the cathode while holes drift to the anode. The electrodes collect the charge. The collected charge produces a current pulse on the electrode, whose integral equals the total charge generated by the incident particle (which is a measure of the deposited energy). The readout goes through a charge sensitive amplifier and then to a shaping amplifier. These detectors are usually placed at a close proximity to the collision points.

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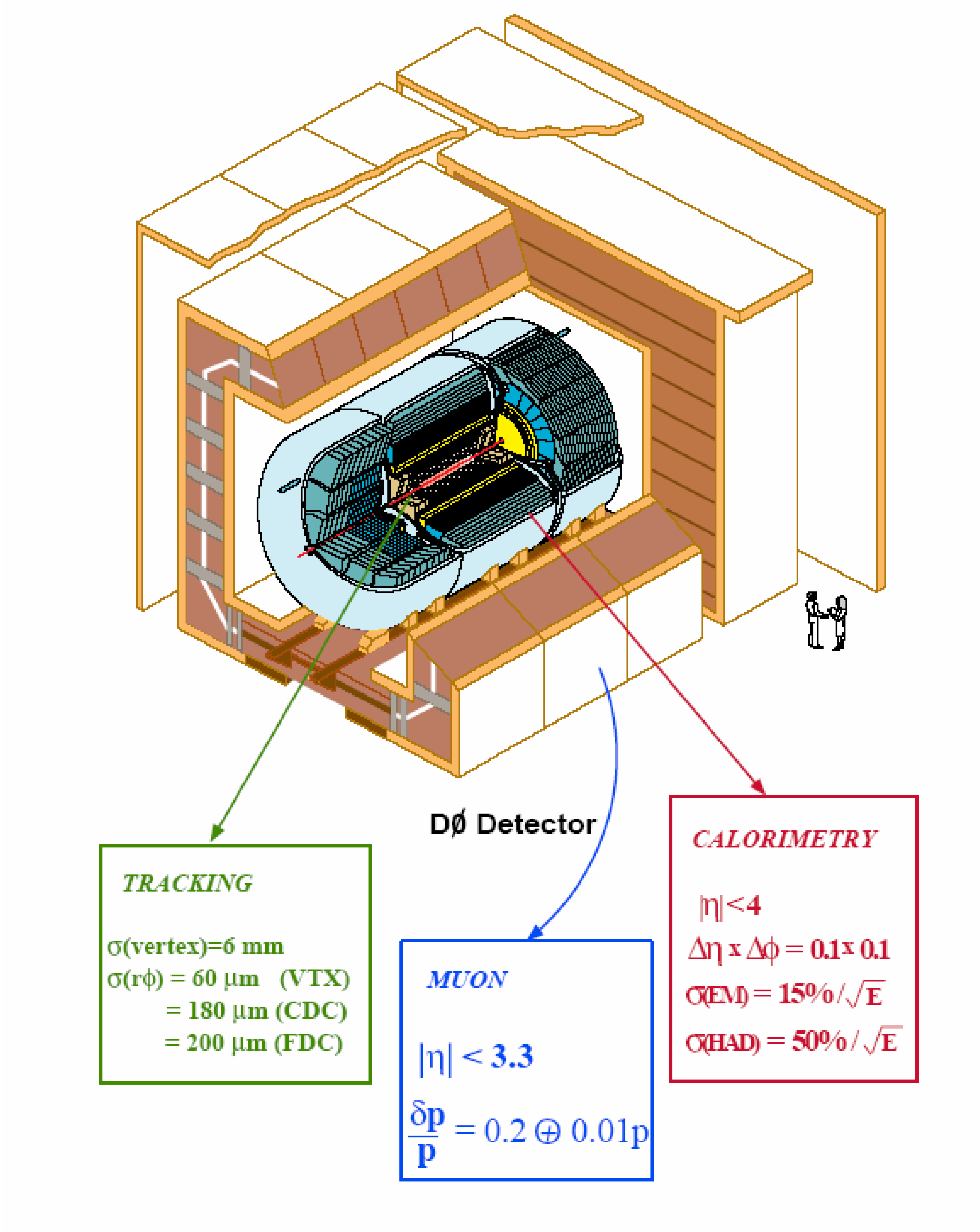


Figure 1-D0 detector

Electronics are a key component of all modern detector systems. Although experiments and their associated electronics can take very different forms, the same basic principles of the electronic read out and optimization of the signal to noise ratio apply to all. The detectors help indicate the tracks created by particles that hit them .The aim of this study is to understand what settings will best reduce the noise. This can only be achieved using a laser for the purpose of our research. A laser basically sends an electrical signal to the detector. This detector is made up of amplifiers. This amplifies the electrical pulse and sends it to an ADC (Analog to digital converter). This digitizes the signal and stores it for subsequent analysis.

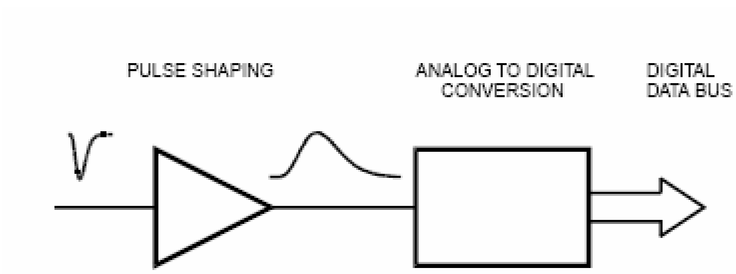
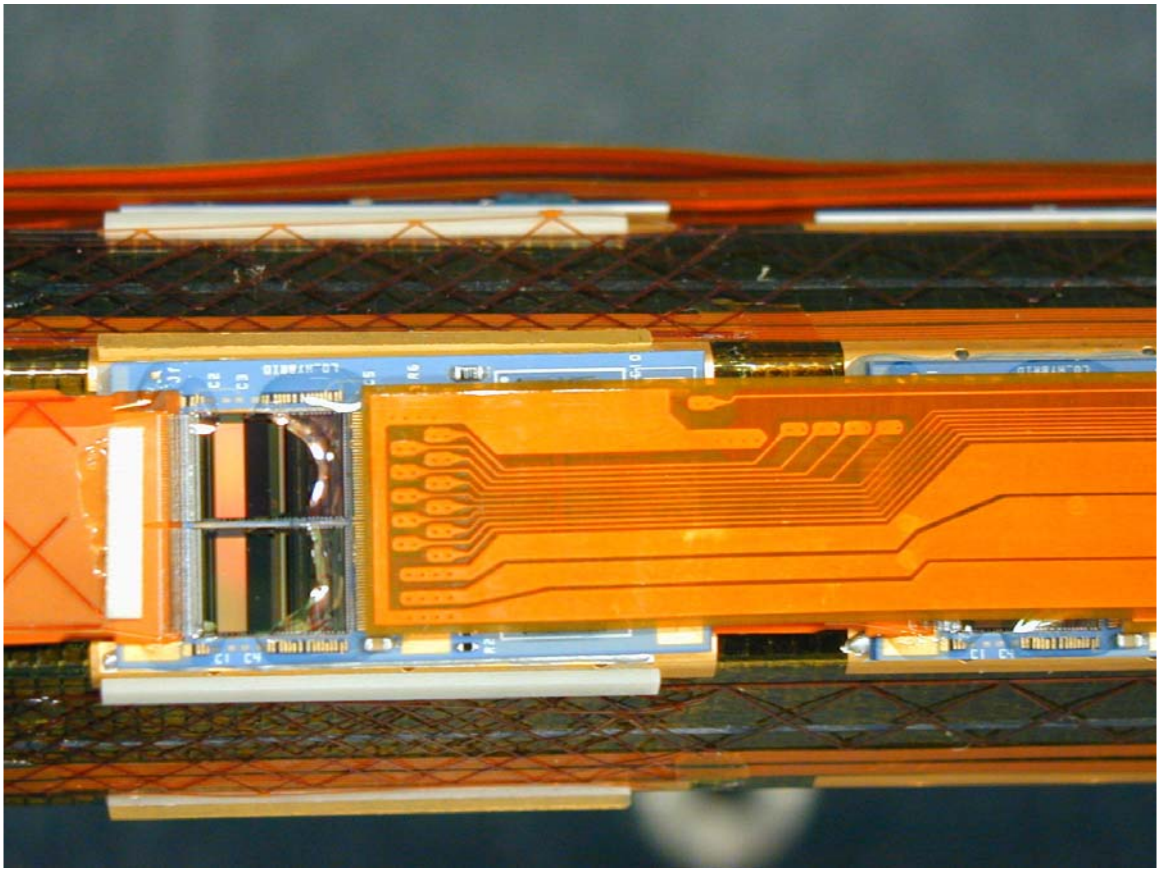


Figure 2-steps to read out

Theory: A module consists of a detector connected to a hybrid via a cable made up of 256 read out strips (128 per chip). Therefore, it contains 256 amplifiers. In principle, the bandwidth settings and the Pre-amp current affect the way in which these detectors respond to a signal



pulse.

Figure 3- silicon detector hybrid

The Sensor Signal:

This is usually a short current pulse fired through the laser. The study involved a laser firing on the detector, which contains pre-amplifiers (charge sensitive amplifiers). A noticeable change in the pulse was observed when the pre-amp bandwidth setting was varied. At a bandwidth setting of zero, the amplifier responds fastest, and the noise level was observed to be high. Also, at a bandwidth setting of 15, (highest bandwidth setting, because the bandwidth setting is 4-

bits) the amplifier responds the slowest and the noise level were significantly reduced.

Varying the pre-amplifier current, also affects the way the amplifier responds to a laser pulse.

What is electronic noise?

Noise is the fluctuations in and the addition of external factors to the signal being received at a detector. It is mostly an undesired interference with intended operations. All electrical activity, which is not the signal you want, is considered noise. If you have much noise, then it becomes difficult to distinguish the signal from the noise. There are various types of noise; one type of noise is referred to as shot noise.

Shot noise: This involves electrical fluctuations in a conductor. This is caused by the fact that current is carried by discrete charges. The strength of this noise increases for growing magnitude of the average current flowing through the detector.

It is highly important that in a silicon detector, low noise level electronics is used because there is no charge multiplication in silicon, and the signal being looked for, is a charge. Hence the signal that can be obtained from the detector is one in which the noise level is a minimum.

Variation in the settings significantly affects the noise level; therefore it is important to know how these settings affect the noise level in the detector. During the test of these detectors, 2 major settings affected the noise level: The bandwidth settings and the pre-amp current settings.

How does Bandwidth variation affect the noise in the detector?

Considering the circuit for a detector front-end:

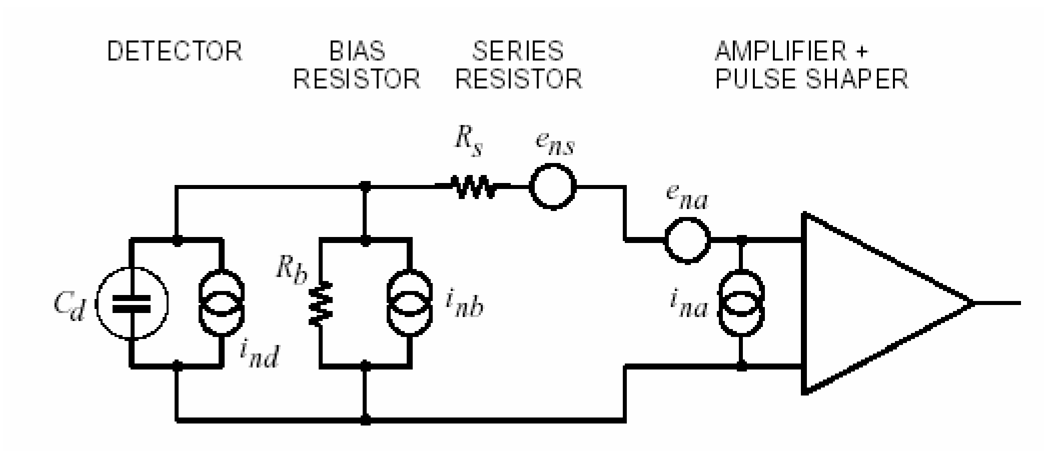


Figure 4-example circuit of a detector front-end

In order to analyze this circuit, we assume this is a voltage amplifier; so all noise contributions are treated as noise voltage. In principle, resistors can either be modeled as a current or voltage generator. Generally, resistors shunting the input act as noise current sources and resistors in series with the input act as noise voltage sources. The noise of the amplifier is a combination of all the current and voltage noise sources at its input.

Therefore, the noise sources are:

Sensor bias current: $i_{nd}^2 = 2q_e I_d$ where q_e is the electronic charge.

Shunt resistance: $i_{nb}^2 = \frac{4kT}{R_b}$

Series resistance: $e_{ns}^2 = 4kTR_s$

Amplifier noise parameters: e_{na} and I_{na}

q_e is the electronic charge, I_d is the sensor bias current and k is the Boltzmann constant. Although the fundamental sources of noise are current and voltage, it is easier to express the system's noise level as an equivalent noise charge.

Its value is given by the equation below:

$$Q_n^2 = \left(\frac{e^2}{8}\right)\left[\left(2q_e I_d + \frac{4kT}{R_b} + i_{na}^2\right)\cdot \tau + \left(4kTR_S + e_{na}^2\right)\cdot \frac{C_d^2}{\tau} + 4A_f C_d^2\right].$$

In principle, increasing the bandwidth increases the rise time. This equation is divided into three parts. The first is relatively small and its contribution is small. The second section of the equation is dominant and hence affects the noise level significantly. This explains why increasing the bandwidth results in a lower noise level. Increase in the bandwidth consequently increases the rise time, from the second part of the above equation, we can observe that an increased rise time will result in a lower noise level.

How does a Bias Voltage affect the noise level?

From the third section of the above equation, we can deduce that the input capacitance could affect the noise level.

From the equation **Q=CV**, **we can deduce that the lower the voltage, the higher the capacitance**. If a bias voltage is absent, what we will see is a high capacitance; this can make the third part of the equation significant and hence increase the noise level.

Note: If there is no bias voltage, the capacitance never increases to infinity, as the equation above will prove. Instead, there is always a depleted region (region in which no charge carriers are free to move) even when no voltage is applied. This region serves as a kind of parallel plate capacitor whose distance is small. When a voltage is applied, it has the effect of extending the depleted region, hence increasing the distance. The equation **$C=\varepsilon_0 A/d$ where ε_0** Permitivity and d is the distance between the depleted region shows that there will be more noise when there is no voltage when compared to the noise level after a voltage is applied. This is due to the fact that the shorter the distance between the depleted region, the higher the capacitance and as such the noise increases after employing the equation for the equivalent noise charge and vice versa.

Variation of time delays:

Varying the delay time helps in studying the pre-amplifier's response. It helps us to check how fast or slow the pre-amplifier collects and shapes the electrical signal. In principle, changing the delays will affect the pulse signal. A graph of the delay time and the signal helps to calculate the fall or rise times, which consequently gives the noise level. Specifically the delay is the time it takes to obtain a digitized output after the laser fires on the detector.

Experiments:

- Apparatus and procedures

The equipment used consists of a laser scanner mounted on a mechanical frame. It is on the frame that the module is placed.

There is also an electronic circuit board know as the purple card. The module is fitted on the purple card. A crate consisting of a stand-alone sequencer, high voltage slot and a computer were used. A software known as the MS SVX4 was used to read out the chips. This software is basically a visual basic program using a Microsoft excel interface. The software reads out the chips and returns a digitized output. The software is used to make changes in any parameter setting on the chip. A screenshot of the most important sheet of the software used is shown in fig 5.

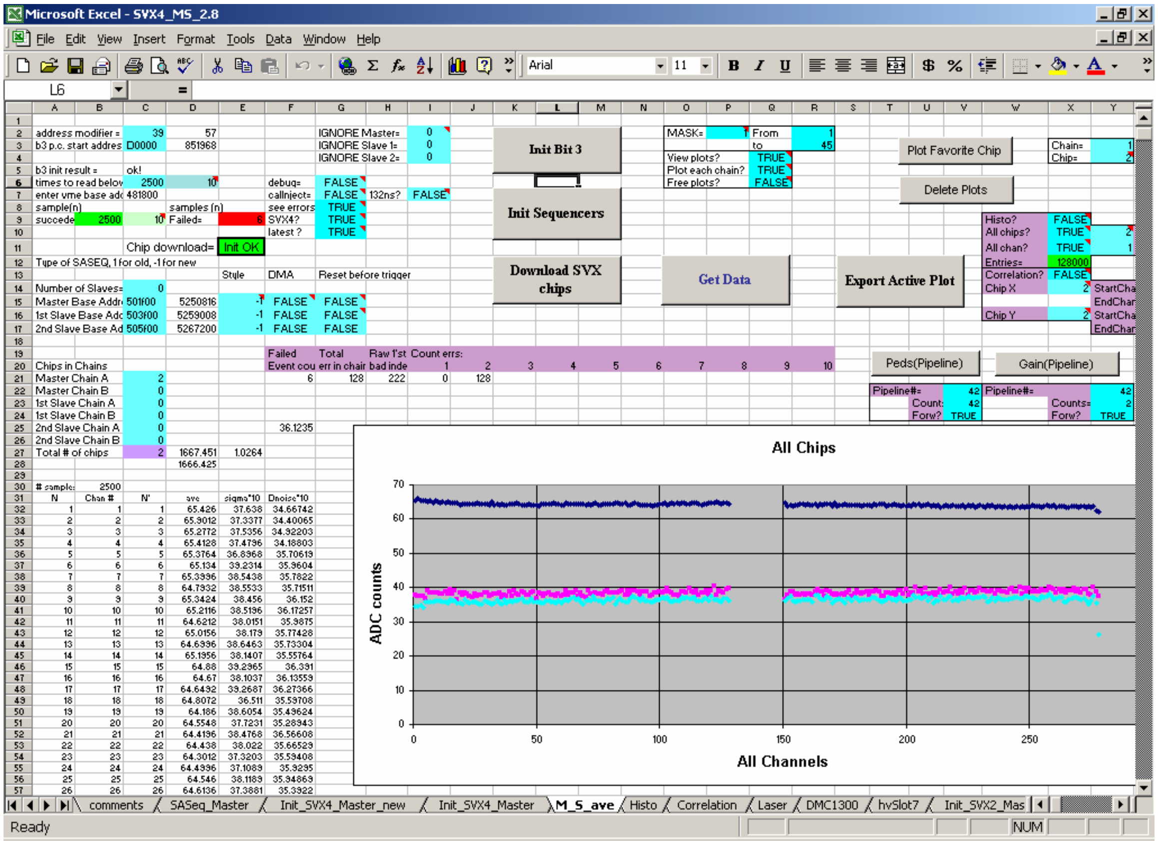


Figure 5-screen shot of the MS SVX4 program

For every test of a module (a complete detector connected to the hybrid), the purple card must be activated; LED's at the front of the device indicates this. Parameter settings can be changed as desired via the software, and then a read out taken, this returns values that are later analyzed by mainly graphing.

Also, a trigger device linked to an oscilloscope provided a means by which I could vary the delay.

Results: Each test involved a change in the parameter settings that yielded certain values. The average noise for each bandwidth and current settings was measured and the values obtained were plotted.

A graph of the pre-amplifier current is shown in figure 6.

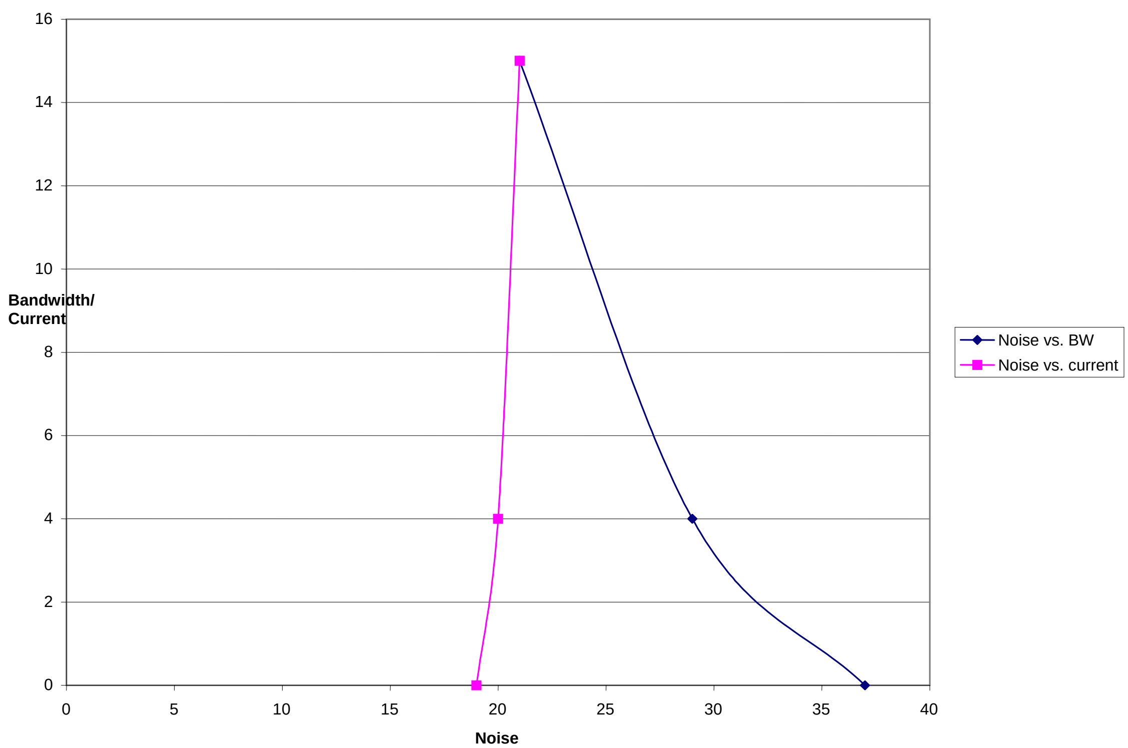


Figure 6-graph of noise versus bandwidth/current

In the figure above, two important points can be deduced: the noise increases as the current increases, but only slightly. Also as the bandwidth increases, the noise reduces. This behavior of the amplifier fits perfectly into the theoretical principle.

Variation of delay times:

As previously stated, varying the delay time helps in understanding the response of the detector. A graph showing delay against signal can give us an idea of the rise or fall time. The nature of the graph provides an insight as to how the detector is responding to a signal.

This is illustrated below, in the next two graphs.

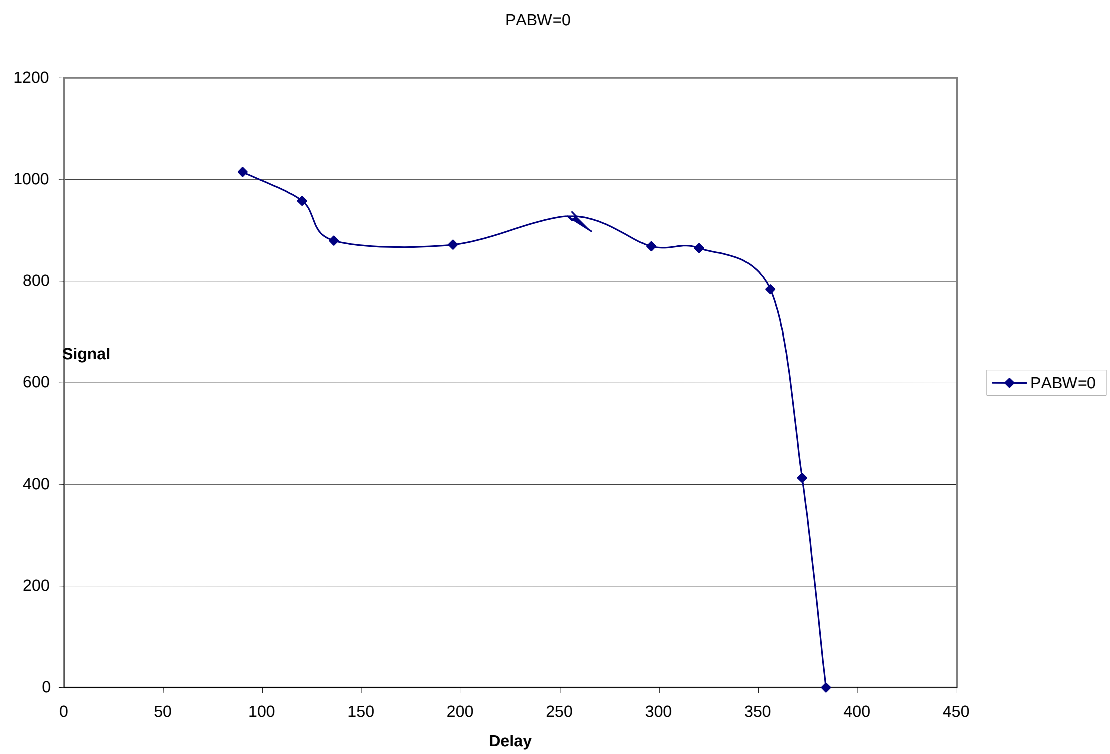


Figure 7-signal vs. delay

Fig 7 is a graph of signal against delay time. The top of the graph is somewhat irregular and indicates that there is some bouncing around in the detector. This further reveals that some bad events are occurring during read out. In order to avoid this, fewer events were taken and this greatly helped the situation.

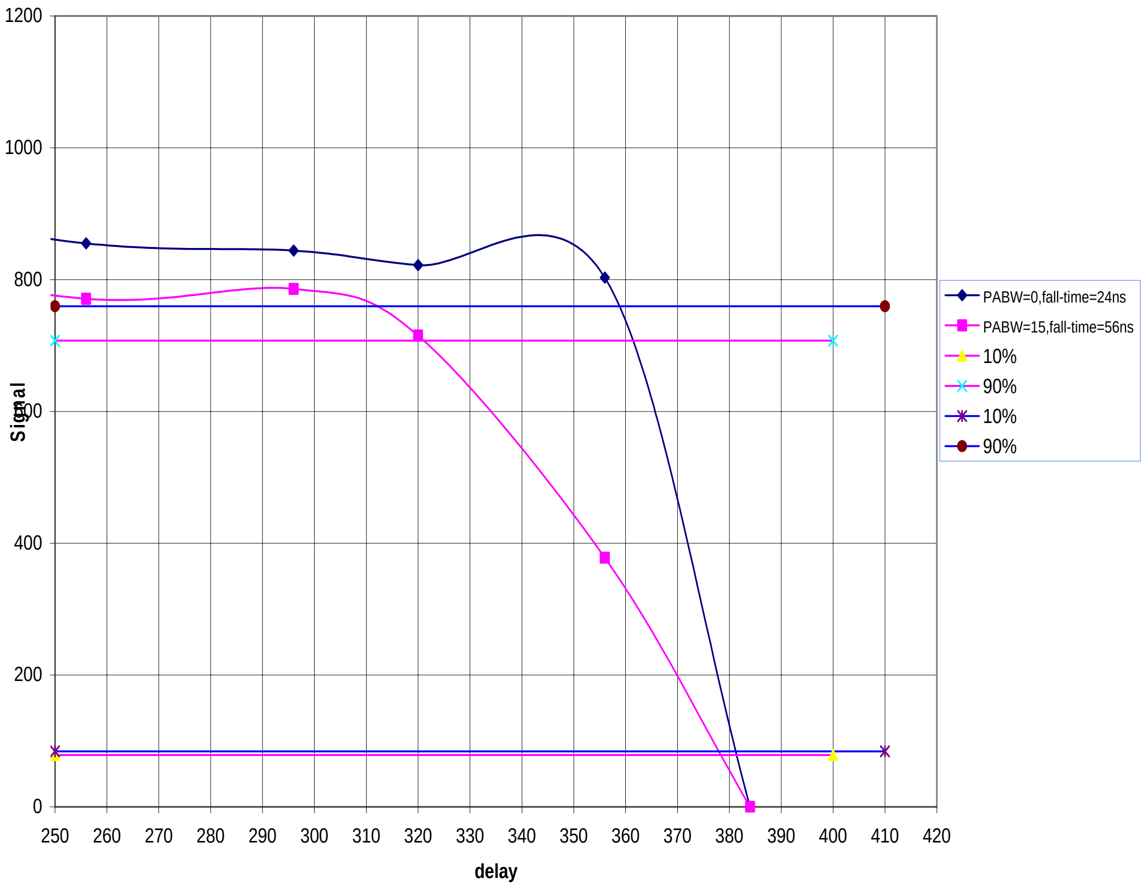


Figure 8-signal vs. delay

Fig 8 shows how the fall time is calculated for different pre-amplifier bandwidth settings.

It can be seen from the slopes of each graph that at a bandwidth setting of 0, the fall time is much shorter than at a bandwidth setting of 15. This indicates at a bandwidth of zero, the detector amplifier responds the fastest but with more noise, due to the short fall time. At a bandwidth of 15, it responds the slowest with less noise.

Theoretically, increasing the bandwidth slows the amplifiers response but with a low noise level, while on the other hand, using a small bandwidth increases the amplifier's response but with a higher noise level. This was confirmed by all experimental tests on the detector using a laser to fire little electric signals on the detector. Fig 8 indicates that the detector obeyed all theoretical predictions. Events will be taken every 396ns during the run of the experiment. Noise will be minimized as much as possible as the experiment requires low noise electronics.

Conclusion:

Reducing the detector capacitance, selecting all resistances in the input circuit, and choosing the optimum shaping time constant improve noise. The noise parameters of a well-designed amplifier depend primarily on the input device. Generally, fast high gain transistors are best. In field effect transistors, noise current contributions are small; therefore increasing the bias resistance will allow long shaping times with correspondingly lower noise. The transconductance (g_m), which is an expression of the performance of the transistor, increases with increasing preamplifier current. Minimum noise is obtained when the transconductance is maximum, $e_n^2 \approx 4kT / g_m$,

where e_n is noise voltage.

The modules have been installed on a carbon rod in readiness to be installed in the D0 machine. The detector implements low noise electronics, and as such they have a good resolution.

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References:

1. Helmut Spieler. “Front-End electronics and signal processing”.
2. D0 experiment “www-D0.fnal.gov/public/detectors.html”.